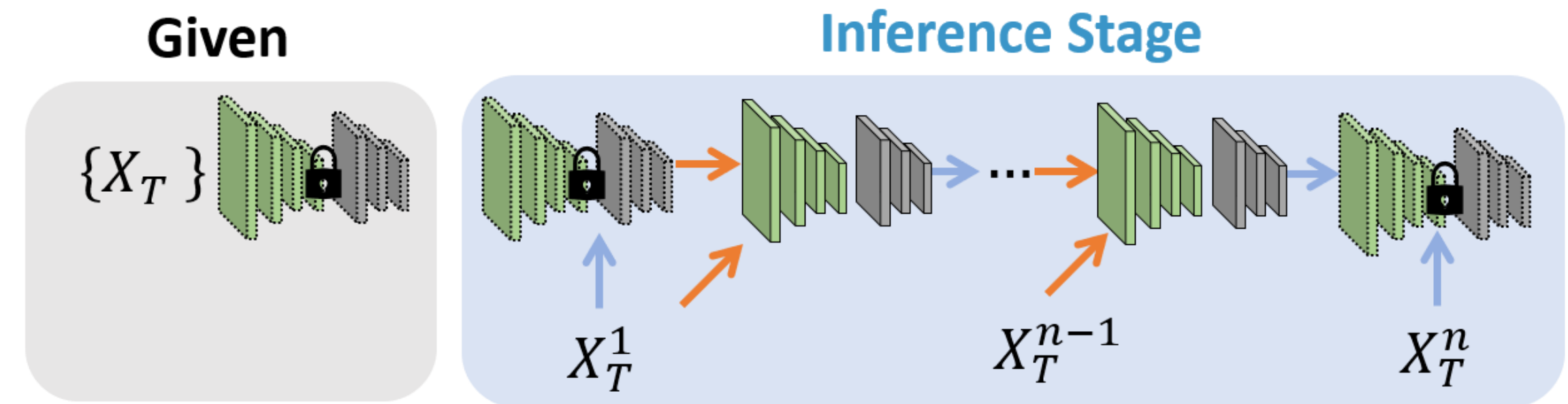


## Face Anti-Spoofing (FAS)

### Fully Test-Time Adaptation (TTA)



~~{X<sub>S</sub>, Y<sub>S</sub>}~~: Label source dataset → Training → Testing  
{X<sub>T</sub>} : Unlabeled target dataset {X<sub>T</sub>} = {X<sub>T</sub><sup>1</sup>, X<sub>T</sub><sup>2</sup>, ..., X<sub>T</sub><sup>n</sup>}

### Challenges in TTA Setting

- Noisy pseudo-label problem
- Class imbalance within a batch of target data
- Unseen attack types

### Goal

- To obtain reliable pseudo labels
  - Via fine-grained activation map
- To prevent overfitting to one dominant class
  - Via memory bank
- To detect unseen attack types
  - Associate unseen attacks with seen attacks

## 3A-TTA Framework

### Activation-Based Pseudo-Labeling

- Pseudo label
  - Similarity between liveness feature and class activation map
- $$\bar{y} = \begin{cases} 1, & \text{if } \text{sim}(\mathbf{f}, \mathbf{A}_l) \geq \text{sim}(\mathbf{f}, \mathbf{A}_s); \\ 0, & \text{if } \text{sim}(\mathbf{f}, \mathbf{A}_l) < \text{sim}(\mathbf{f}, \mathbf{A}_s); \end{cases}$$

### Liveness loss

$$\mathcal{L}_l = -\sum \bar{y} \log \text{CF}(\mathbf{f}) + (1 - \bar{y}) \log(1 - \text{CF}(\mathbf{f}))$$

### Anti-Forgetting Feature Learning

- Reliable feature selection

$$\gamma = \begin{cases} 1, & \text{if } \begin{cases} \text{CF}(\mathbf{f}) > \alpha & \text{and } m_{\text{sim}} \geq \beta; \\ \text{CF}(\mathbf{f}) < 1 - \alpha & \text{and } m_{\text{sim}} \leq -\beta; \end{cases} \\ 0, & \text{otherwise} \end{cases}$$

- Anti-forgetting liveness loss

$$\mathcal{L}_{afl} = -\sum \hat{y} \log \text{CF}(\hat{\mathbf{f}}) + (1 - \hat{y}) \log(1 - \text{CF}(\hat{\mathbf{f}}))$$

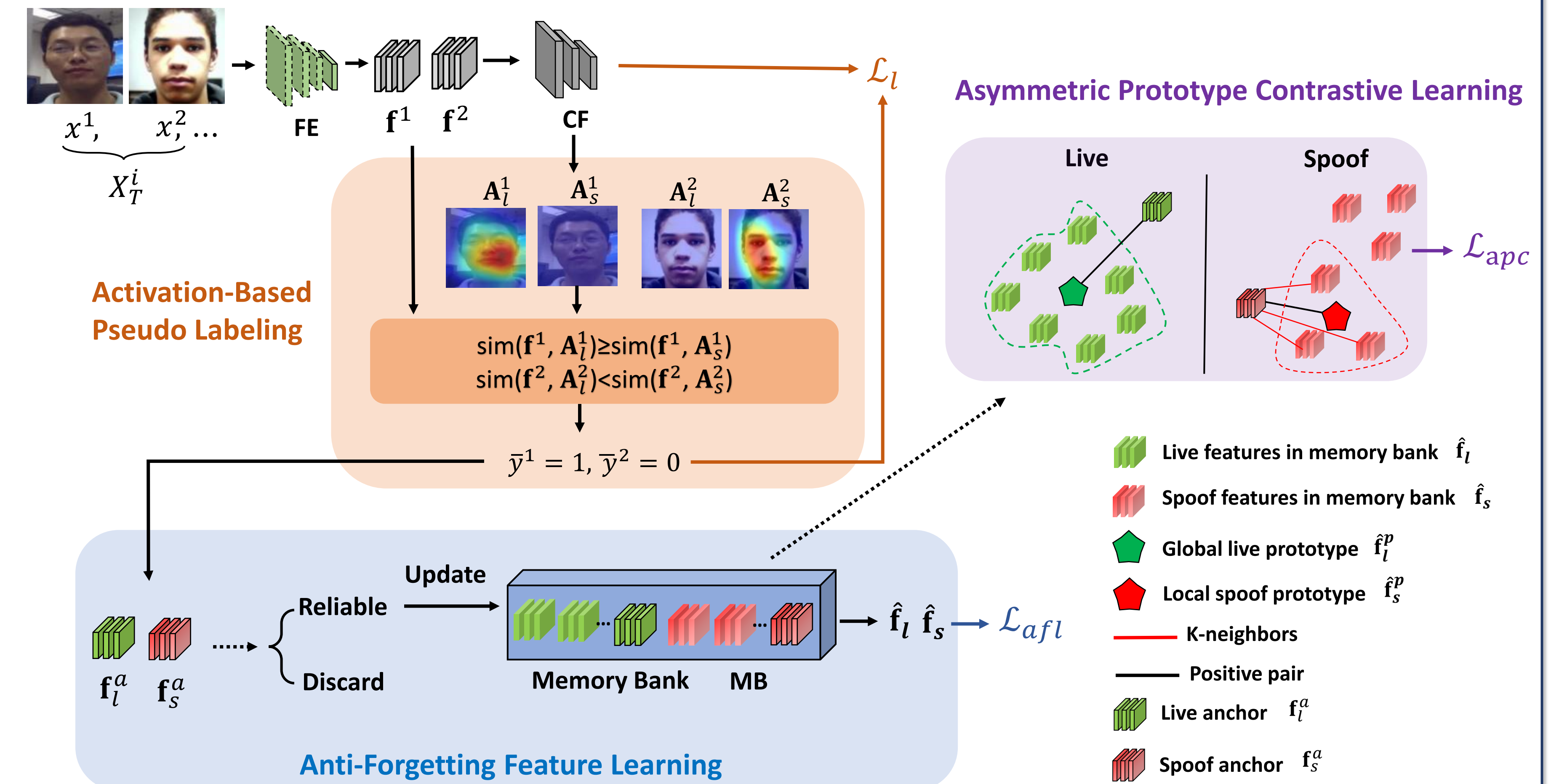
### Asymmetric Prototype Contrastive Learning

- Asymmetric prototype contrastive loss

$$\mathcal{L}_{apc} = -\log \frac{\exp(\text{sim}(\mathbf{f}_s^a, \hat{\mathbf{f}}_s^p))}{\sum_{j \in \{\hat{\mathbf{f}}_s^p \cup \mathbf{f}_l\}} \exp(\text{sim}(\mathbf{f}_s^a, \hat{\mathbf{f}}^j))} - \log \frac{\exp(\text{sim}(\mathbf{f}_l^a, \hat{\mathbf{f}}_l^p))}{\sum_{j \in \{\hat{\mathbf{f}}_l^p \cup \mathbf{f}_s\}} \exp(\text{sim}(\mathbf{f}_l^a, \hat{\mathbf{f}}^j))}$$

### Total Loss

$$\mathcal{L}_T = \mathcal{L}_l + \lambda_1 \mathcal{L}_{afl} + \lambda_2 \mathcal{L}_{apc}$$



## Experiments

### Datasets

- OULU-NPU (O), MSU-MFSD (M), CASIA-MFSD (C), Replay-Attack (I), 3DMAD (D), and HKBU-MARs (H)

### Evaluation Metrics

- Half Total Error Rate (HTER) ↓
- Area Under Curve (AUC) ↑

### Proposed TTA-FAS Benchmark

Protocol	Subset	Attack Type	Real data (V/I)	Attack data (V/I)	All data (V/I)
[O,C,I] → [M,D,H]	Source: OCI	print, replay	1280	5110	6390
	Target: MDH	print, replay, 3D Mask	339	355	694
[O,M,I] → [C,D,H]	Source: OMI	print, replay	1200	4360	5560
	Target: CDH	print, replay, 3D Mask	419	595	1014
[O,C,M] → [I,D,H]	Source: OCM	print, replay	1210	4620	5830
	Target: IDH	print, replay, 3D Mask	409	845	1254
[I,C,M] → [O,D,H]	Source: ICM	print, replay	350	1360	1710
	Target: ODH	print, replay, 3D Mask	1259	4105	5364

### Experimental Comparisons

Method	[O,C,I] → [M,D,H]								[O,M,I] → [C,D,H]									
	O,C,I → M	O,C,I → D	O,C,I → H	Average		Time		O,M,I → C	O,M,I → D	O,M,I → H	Average		Time					
	HTER	AUC	HTER	AUC	HTER	AUC	HTER	AUC	HTER	AUC	HTER	AUC	HTER	AUC	HTER	AUC	Time	
No adaptation	26.67	94.49	19.55	88.11	22.15	84.33	22.79	88.98	0.50	28.78	86.26	26.86	87.83	23.47	84.91	26.37	86.33	0.62
Tent [42]	27.98	94.49	22.67	87.44	22.49	84.55	24.38	88.83	1.061	28.14	79.68	46.10	53.69	28.54	79.36	34.26	70.91	1.36
OAP [3]	26.41	94.49	19.79	88.09	22.15	84.35	22.78	87.35	0.55	29.34	86.03	26.86	87.78	22.95	85.86	25.38	86.55	0.70
3A-TTA	<b>26.21</b>	<b>94.53</b>	<b>16.26</b>	<b>92.03</b>	<b>20.89</b>	<b>84.74</b>	<b>21.12</b>	<b>90.43</b>	4.35	<b>23.55</b>	<b>87.29</b>	<b>17.21</b>	<b>90.63</b>	<b>20.33</b>	<b>86.99</b>	<b>20.36</b>	<b>88.30</b>	7.12
	[O,C,M] → [I,D,H]								[I,C,M] → [O,D,H]									
Method	O,C,M → I	O,C,M → D	O,C,M → H	Average		Time		I,C,M → O	I,C,M → D	I,C,M → H	Average		Time					
	HTER	AUC	HTER	AUC	HTER	AUC	HTER	AUC	HTER	AUC	HTER	AUC	HTER	AUC	HTER	AUC	Time	
No adaptation	30.36	71.22	25.27	83.89	19.93	90.08	25.19	81.73	0.71	37.73	81.95	25.80	<b>81.79</b>	34.93	83.88	32.82	<b>82.54</b>	2.28
Tent [42]	35.73	70.16	25.43	84.12	22.28	89.81	27.81	81.36	1.57	47.01	64.23	26.43	80.11	42.43	83.40	38.62	75.91	8.72
OAP [3]	29.69	71.15	25.15	83.81	19.93	90.09	24.92	81.68	0.81	31.21	78.50	25.62	81.55	35.41	83.65	30.75	81.23	2.28
3A-TTA	<b>28.11</b>	<b>72.45</b>	<b>21.78</b>	<b>86.28</b>	<b>16.99</b>	<b>90.36</b>	<b>22.29</b>	<b>83.03</b>	8.72	<b>25.62</b>	<b>82.25</b>	<b>24.35</b>	80.06	<b>30.71</b>	<b>84.41</b>	<b>26.89</b>	82.24	37.06

### Ablation Study

Method	Total Loss $\mathcal{L}_T$				pseudo-labeling Mechanisms			Feature Selection	[OMI] → D		[OMI] → C	
	$\mathcal{L}_l$	$\mathcal{L}_{afl}$	$\mathcal{L}_{apc}$	$\mathcal{L}_c$	Score based	Class Prototype based	Activation based		HTER	AUC	HTER	AUC
M0								26.86	87.83	28.78	86.26	
M1	✓							23.19	88.41	29.78	85.05	
M2	✓					✓		27.72	88.28	30.24	86.05	
M3	✓						✓	21.87	88.68	26.02	86.44	
M4	✓	✓					✓	19.31	88.49	24.94	86.29	
M5	✓	✓					✓	18.15	89.47	24.33	87.07	
M6	✓	✓		✓			✓	18.20	87.78	26.00	86.56	
M7	✓	✓	✓				✓	<b>17.21</b>	<b>90.63</b>	<b>23.55</b>	<b>87.29</b>	

### T-SNE Visualization

